Oxyfluorfen (Goal®) Trials with Bareroot Forest Seedlings in British Columbia 1987

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SUMMARY

The herbicide oxyfluorfen was evaluated for weed control and crop tolerance on 1-year (1+0) and 2-year (2+0) Douglas-fir and lodgepole pine bareroot seedlings. Oxyfluorfen was applied at 0.25, 0.50, and 1.00 kg a.i/ha before emergence or budbreak of the conifer seedlings and 3 and 6 weeks after emergence or budbreak.

In the 1+0 trial area, broadleaved weed infestation was heavy but grasses were light. Oxyflurofen when applied pre-emergence resulted in excellent weed control, and when applied 3 weeks after seedling emergence gave acceptable control at the 0.50 and 1.00 kg a.i./ha rates. The results were poor at 6 weeks seedling post-emergence. All pre- and post-emergence applications reduced the number of 1+0 fir seedlings. In 1+0 pine, reductions in seedling numbers were found only at the 0.50 and 1.00 pre-emergence and 0.50 kg a.i./ha 6 weeks post- emergence applications. All post-emergence treatments, except when oxyfluorfen was applied at 0.25 kg a.i./ha 3 weeks after seedling emergence, caused visible injury in pine. The 1.00-kg a.i./ha rate at 3 weeks post-emergence was the only treatment visually rated not satisfactory for fir. All treatments caused a reduction in the height of pine. In fir, seedling height was reduced by all treatments except the 0.25 and 0.50 pre-emergence applications. Post-emergence treatments reduced root collar diameter and dry shoot and root weight in both pine and fir.

In the 2+0 trial area, both fir and pine showed good tolerance to all treatments of oxyfluorfen.

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INTRODUCTION

In British Columbia, herbaceous weeds are a serious problem in forest nurseries. They affect the growth and survival of seedlings by reducing the efficiency of fertilizers and irrigation, and they may harbour tree-damaging insects and pathogens. At present, nurseries use both traditional herbicides and hand-weeding to mitigate the effects of weeds. Hand-weeding is time consuming and expensive.

A promising herbicide which has been registered for use in U.S. forest nurseries since 1979 is oxyfluorfen (Goal®). It is a diphenyl ether herbicide, with broad spectrum pre- and post-emergence activity against many broadleaf weeds and grasses commonly found in forest nurseries. Working as a contact herbicide, it induces lipid peroxidation, whereby oxygen reacts directly with polyunsaturated fatty acids to form free radical intermediates and produce semi-stable peroxides (Kunert *et al.* 1985). In the process, cell components such as proteins, enzymes, and pigments are damaged by the free radicals that result from the peroxidation. This leads to the pigment bleaching or a "burn" response observed with herbicide phytotoxicity (Sandmann and Boger 1983).

Oxyfluorfen has many characteristics that make it suitable for nursery environments. For example, it has very low solubility in water (< 0.1 ppm) and is strongly adsorbed on soils (Jaeger 1986). This makes it an ideal residual herbicide on treated soils, regardless of precipitation or irrigation. Although it requires light for activation (Vanstone and Stobbe 1979), it moves very little from either root or foliar applications, and is not readily metabolized in plants. It is non-corrosive, compatible with most other pesticides, and free of storage problems. As well, oxyfluorfen has extremely low mammalian toxicity, with an acute oral LD_{50} of >5000 mg/kg (Thompson 1983).

Numerous conifer species have a high degree of tolerance to a variety of oxyfluorfen rates. In the southern U.S., six pine species (*Pinus taeda* L., *P. elliottii* Englem., *P. echinta* Mill, *P. palustris* Mill *P. virginiana* Mill, and *P. strobus* L.) exhibited no visual injury and no reduction in germination or growth at rates of 0.56 - 1.13 kg a.i./ha (South and Gjerstad 1980). Douglas-fir (*Pseudotsuga menziesii* (Mirb.)Franco), lodgepole pine (*Pinus contorta* Dougl. ex Loud.), western redcedar (*Thuja plicata* Donn), and Sitka spruce (*Picea sitchensis* (Bong.)Carr) have shown good to excellent tolerance to pre- and post-emergence applications of oxyfluorfen at rates of 0.125 - 3.00 kg a.i./ha (Delaney and Moon 1984; Mason and Sale 1984; Meakin and Orpin 1984; Richardson *et al.* 1984; Turner and Clipsham 1984).

On the basis of its potential and extensive use in nurseries in the United States, oxyfluorfen was chosen by the Canadian Forest Nursery Weed Management Association (CFNWMA) as a candidate for registration. A standardized oxyfluorfen trial was designed by the Association to facilitate and co-ordinate weed control and crop tolerance data from different regions of Canada. The trials were conducted across the country, and provided information on: 1) the tolerance of 1+0 and 2+0 bareroot Douglas-fir and lodgepole pine to oxyfluorfen; and 2) the degree of herbicide efficacy in controlling weeds commonly found in British Columbia forest nurseries.

MATERIALS AND METHODS

The trial was established in 1987 at Surrey Nursery, B.C. Ministry of Forests, near Vancouver, B.C. Mean monthly precipitation and temperatures at the nursery for 1987 are presented in Figure 1. The trial was conducted on 1-year-old (2+0) and newly sown (1+0, April 2, 1987) coastal Douglas-fir and interior lodgepole pine. Both age groups and species were grown in raised seedbeds in well-drained, sandy loam soils (65% sand, 25% silt, 10% clay, 3.3 - 4.6% organic material, pH 4.2-4.8). All seedlings were subject to standard nursery irrigation and fertilizer applications throughout the growing season (B.C. Ministry of Agriculture and Fisheries 1987), as well as to any necessary insecticide sprays (Diazinon® and Orthene®). No other herbicides were used in the 1+0 seedbeds, but simazine had been applied in the fall of 1986 in the 2+0 seedbeds. As outlined by the CFNWMA, 11 treatments consisting of hand-weeded and non-weeded controls and oxyfluorfen applied at three rates (0.25, 0.50, and 1.00 kg a.i./ha) and timings were set up in a randomized complete block design with four replicates. The plots were 3.0 X 1.2 m, with a 1.0-m buffer between. The oxyfluorfen applications were made before and then 3 and 6 weeks after seedling emergence or budbreak in the 1+0 and 2+0 seedlings, respectively. To maintain all weeded controls and buffers, weeds were pulled by hand throughout the season.

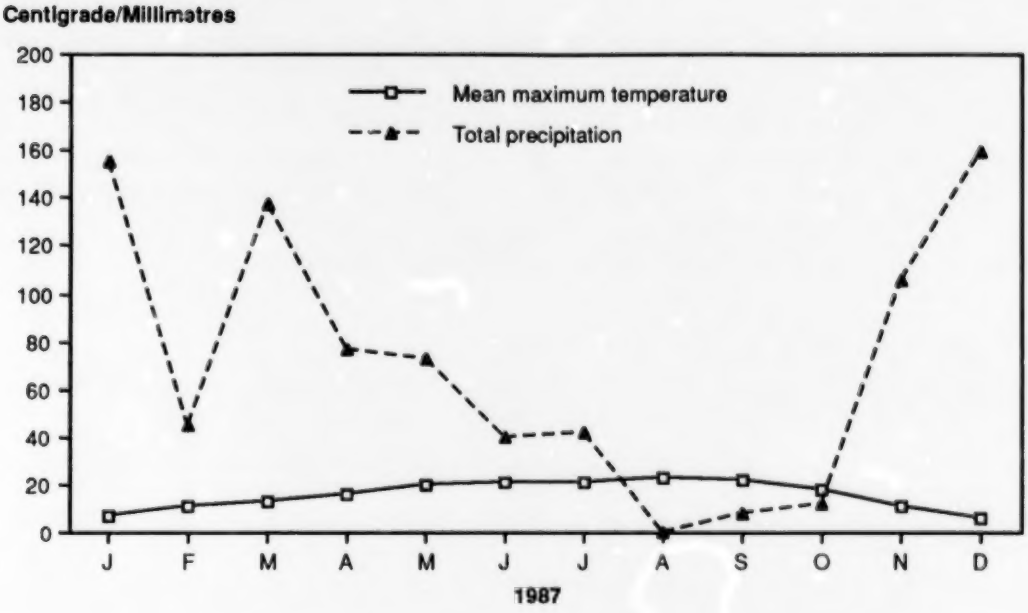

FIGURE 1. Monthly mean maximum temperature and total rainfall at Surrey Nursery, 1987

The oxyfluorfen formulation used was an emulsifiable concentrate with 192 g a.i./L of product. The herbicide was supplied by Rohm and Haas Chemical Ltd. All applications were made with a CO_2 pressure-regulated R & D backpack sprayer fitted with three (TeeJet) 8003 flat fan nozzles. Oxyfluorfen was applied approximately 46 cm above the seedlings at 1100 L/ha and a pressure of 210 kPa, except for the pre-emergence applications on the 2+0 seedlings which were sprayed at 173 kPa.

The dates and weather conditions for each oxyfluorfen application are summarized as follows:

Seedling age	Species	Time of application	Date	Conditions
2+0	Douglas-fir	Pre budbreak	19/4/87	overcast, 11° C
		3 wk post-budbreak	08/5/87	sunny, 28° C
		6 wk post-budbreak	04/6/87	sunny, 25° C
	lodgepole pine	Pre-budbreak	17/4/87	sunny, 12° C
		3 wk post-budbreak	13/4/87	overcast, 17° C
		6 wk post-budbreak	05/5/87	sunny, 23° C
1+0	Douglas-fir and lodgepole pine	Pre-emergence	05/4/87	overcast, 16° C
		3 wk post-emergence	13/5/87	sunny, 18° C
		6 wk post-emergence	03/6/87	sunny, 25° C

Approximately 10 weeks after either budbreak or seedling emergence, weed assessment was taken on the 2+0 pine and fir plots on June 5 and 25, 1987, respectively, and from June 29 to July 1, 1987, in both the 1+0 pine and fir. A weed control rating system was used based on a scale of 0-10, in which 0 indicated no control with a dense stand of weeds present and 10 indicated complete control. A total of 34 weed species were identified from the control and treatment plots of 1+0 pine, 33 in the 1+0 fir plots, 11 in the 2+0 pine plots, and 16 in the 2+0 fir plots (Table 1) (Franklin and Mulligan 1970; Hitchcock and Cronquist 1973). They were removed carefully by hand and weighed fresh by species. All plots were then hand-weeded during the rest of the season.

Seedling counts, plant tolerance ratings, and seedling sample extractions were conducted in 1987: September 14-17 on 2+0 pine; October 1-2 on 2+0 fir; and October 26-30 on 1+0 pine and fir. At these dates, the seedlings had or were about to set bud. For the plant tolerance rating, a visual assessment was used with a scale of 0-10, in which 0 indicated no tolerance and severe injury, and 10 indicated complete tolerance and no injury. Seedlings were counted with the use of a 0.25-m^2 counting frame placed across the bed, 50 cm in from the beginning and end of each plot. The 2+0 seedlings had also been counted before the first oxyfluorfen application in March. Year-end, post-treatment growth data were determined from 40 seedlings, collected from each treatment plot in groups of 10 from every other row in a stepwise fashion. The samples were stored at 4°C in the nursery storage facility, and then measured for root collar diameter and shoot height. Shoots were subsequently clipped from the roots and placed separately in brown paper bags in groups of five roots or shoots per replicate per bag. Samples were weighed after oven drying at 60°C for 48 hr.

All but the major weed species data were analysed with the use of ANOVA models and Duncan's multiple range comparison test (Zar 1984). Visual ratings were not subjected to statistical analysis because of their nonparametric nature, and because differences between treatments were evident. Photographs were taken of representative plots in the 1+0 trial (Appendix 1).

TABLE 1. List and occurrence of weed species found in the bareroot conifer seedling oxyfluorfen trials

Common name	Scientific name	2+0		1+0	
		fir	pine	fir	pine
Alkalai sandspurry	*Spergularia diandra* L.	X	X	X	X
Black medick	*Medicago lupulina* L.	X	X	X	X
Broad-leaved plantain	*Plantago major* L.			X	X
Bull thistle	*Cirsium vulgare* (Savi)Tenore	X			X
Canada thistle	*Cirsium arvense* (L.)Scop	X			
Chickweed	*Stellaria media* (L.)Vill.			X	X
Clover	*Trifolium* sp.	X		X	X
Common groundsel	*Senecio vulgaris* L.	X	X	X	X
Cottonwood	*Populus trichocrapa* T.and G.	X		X	X
Low cudweed	*Gnaphalium uliginosum* L.	X		X	X
Dandelion	*Taraxacum officinale* Weber	X	X		X
Dog mustard	*Erucastrum gallicum* (Willd.)			X	
Fireweed	*Epilobium angustifolium* L.	X	X	X	X
Canada fleabane	*Erigeron canadensis* L.				X
Green smartweed	*Polygonum scabrum* Moench		X	X	X
Hoary vervain	*Verbena stricta* Vent.			X	X
Lady's-thumb	*Polygonum persicaria* L.			X	
Lamb's-quarters	*Chenopodium album* L.		X	X	X
Mouse-eared chickweed	*Cerastium vulgatum* L.			X	X
Mouse-ear cress	*Arabidopsis thaliana* (L.)Heynh.			X	X
Narrow-leaved plantain	*Plantago lanceolata* L.	X		X	X
Pearly everlasting	*Anaphalis margaritacea* (L.)Benth and Hook	X		X	X
Prickly lettuce	*Lactuca scariola* L.		X	X	
Sheep sorrel	*Rumex acetosella* L.	X		X	X
Sedge	*Carex lenticularis* Michx.			X	X
Shepherd's purse	*Capsella bursa-pastoris* (L.)Medic			X	X
Spiny annual sow-thistle	*Sonchus asper* (L.)Hill		X	X	X
Spotted cat's-ear	*Hypochoeris radicata* L.	X	X	X	X
Stinkweed	*Thlaspi arvense* L.			X	X
Striate knotweed	*Polygonum achoreum* Blake			X	X
Tansy ragwort	*Senecio jacobaea* L.			X	X
Tufted vetch	*Vicia cracca* L.			X	X
Wild buckwheat	*Polygonum convolvulus* L.			X	X
White cockle	*Lychnis alba* Mill.			X	X
Wild mustard	*Sinapis arvensis* L.				X
Wild radish	*Raphanus raphanistrum* L.	X		X	X
Creeping yellow cress	*Rorippa sylvestris* (L.)Bess.			X	X
Grasses	Gramineae	X	X	X	X

RESULTS

Weed Control

1+0 bareroot

In both fir and pine, broadleaved weed infestation was high while that by grasses were extremely low (Tables 2 and 4, and Appendix 1.). At the time of assessment, lamb's-quarters and clover accounted for over 80% of the major weeds present in the non-weeded control plots (Tables 3 and 5). The pre-emergence treatments of oxyfluorfen resulted in good to excellent weed control. Post-emergence applications 3 weeks after seedling emergence gave good control at the 0.50 and 1.00 kg a.i./ha rates, with clover and black medick escaping. Plots treated 6 weeks post-seedling emergence showed no reduction in weed numbers (Tables 2 and 4).

2+0 bareroot

In both the 2+0 pine and fir beds, weed growth was minimal and most plots had very few or no weeds at the time of weed control assessment (Tables 6 and 7).

Plant Tolerance

1+0 bareroot

The number of pine seedlings was reduced by pre-emergence applications of oxyfluorfen at 0.50 and 1.00 kg a.i./ha and by the post-emergence treatment applied at the 0.50 rate 6 weeks after seedling emergence. The densities of all other treated seedlings were not different from those of the hand-weeded control (Table 8). Fir seedling densities were reduced by all treatments except the pre-emergence applications at 0.25 kg a.i./ha.

The height of pine seedlings was affected by all treatments, while only the post-emergence applications affected root collar diameter, dry shoot, and root weight (Table 9). The height of fir seedlings was poorly affected only by the pre-emergence application at 1.00 kg a.i./ha (Table 10), but, as with pine, all post-emergence applications reduced root collar diameter, dry shoot, and root weight.

2+0 bareroot

Seedling numbers and growth were not affected by any treatment in both 2+0 pine and fir. The pine showed no visual symptoms of injury. In the fir, the 1.00 kg a.i./ha treatment at 3 and 6 weeks after budbreak caused some foliar burn, but recovery was rapid.

TABLE 2. Mean number of weed species in 1+0 lodgepole pine plots at three rates and timings of oxyfluorfen application (n=4)

Treatment (kg a.i./ha)	Timing[1]	Weed control rating (0-10)	Broadleaf		Grass	
			numbers per plot[2]	weight per plot (kg)	numbers per plot	weight per plot (g)
Hand-weeded	—	10.0	—	—	—	—
Non-weeded	—	0.0	223.3 a[3] ± 52.8	11.3 a ± 1.0	1.3 a ±1.5	5.2 c ±10.1
0.25	pre	7.5	58.8 bc ± 49.2	3.5 de ± 3.8	0.3 a ±0.5	0.3 c ± 0.5
0.50	pre	8.3	13.8 c ± 9.2	0.8 ef ± 0.3	0.0 a	0.0 c
1.00	pre	10.0	0.0 c	0.0 f	0.0 a	0.0 c
0.25	post 3-wk	4.8	111.5 b ± 59.4	3.9 cde ± 1.9	1.8 a ±1.0	60.2 a ±28.6
0.50	post 3-wk	8.0	54.8 bc ± 44.2	1.0 ef ± 0.9	1.3 a ±1.9	33.6 b ±42.8
1.00	post 3-wk	8.5	49.3 bc ± 45.5	0.5 ef ± 0.5	0.8 a ±0.5	7.7 bc ± 6.4
0.25	post 6-wk	0.0	204.0 a ± 74.7	7.0 bc ± 5.1	2.3 a ±2.9	11.1 bc ±12.9
0.50	post 6-wk	0.0	206.0 a ± 70.5	8.7 ab ± 1.4	0.5 a ±0.6	6.9 c ± 9.3
1.00	post 6-wk	0.0	247.8 a ± 42.7	6.7 bcd ± 1.7	2.0 a ±0.8	9.2 bc ± 1.7

[1] Timing: pre = before seedling emergence
post 3-wk = 3 weeks post-seedling emergence
post 6-wk = 6 weeks post-seedling emergence

[2] Plot area = 3.6 m^2.

[3] Means followed by the same letter are not significantly different at the 5% level, Duncan's multiple range test.

TABLE 3. Mean number of major weed species per plot for 1+0 lodgepole pine as of June 29-July 1, 1987, at three rates and timings of oxyfluorfen application (n=4)[1]

Treatment (kg a.i./ha)	Timing[2]	Black medick	Clover	Lamb's-quarters	Sedge	Shepherd's-purse	Striate knotweed
Hand-weeded	—	—	—	—	—	—	—
Non-weeded	—	0.0	39.8 ±35.6	140.3 ± 58.7	8.8 ±4.9	3.3 ±0.5	7.3 ±5.6
0.25	pre	18.0 ± 7.3	21.25 ±21.6	14.3 ± 24.5	1.0 ±2.0	0.3 ±0.5	0.3 ±0.5
0.50	pre	3.5 ± 2.4	9.0 ± 9.8	0.3 ± 0.5	0.0	0.0	0.0
1.00	pre	0.0	0.0	0.0	0.0	0.0	0.0
0.25	post 3-wk	17.3 ±10.1	62.5 ±69.9	0.0	5.0 ±5.0	5.8 ±4.9	7.0 ±7.8
0.50	post 3-wk	8.3 ± 4.7	27.5 ±44.4	0.0 ± 0.0	5.5 ±5.3	3.3 ±2.2	1.8 ±1.5
1.00	post 3-wk	4.8 ± 6.9	31.0 ±33.4	0.0 ± 0.0	1.0 ±2.0	2.5 ±1.7	1.0 ±0.8
0.25	post 6-wk	6.8 ± 2.5	16.0 ±14.0	143.8 ±101.5	7.3 ±6.1	1.5 ±1.7	20.0 ±24.4
0.50	post 6-wk	5.3 ± 1.9	24.0 ±19.7	155.8 ± 62.7	1.8 ±1.7	5.0 ±8.0	4.8 ±7.5
1.00	post 6-wk	6.0 ± 6.4	24.3 ±24.6	191.3 ± 72.3	7.0 ±2.2	3.3 ±1.0	2.5 ±2.4

[1] Plot = 3.6 m^2.
[2] Timing: pre = before seedling emergence
post 3-wk = 3 weeks post-seedling emergence
post 6-wk = 6 weeks post-seedling emergence.

TABLE 4. Mean number of weed species in 1+0 Douglas-fir plots at three rates and timings of oxyfluorfen application (n=4)

Treatment (kg a.i./ha)	Timing[1]	Weed control rating (0-10)	Broadleaf		Grass	
			numbers per plot[2]	weight per plot (kg)	numbers per plot	weight per plot (g)
Hand-weeded	—	10.0	—	—	—	—
Non-weeded	—	0.0	317.0 a[3] ± 68.8	11.8 a ± 2.9	3.5 a ±3.3	19.30 bc ±14.8
0.25	pre	8.5	34.5 d ± 20.8	2.1 d ± 0.8	0.0 a	0.0 c
0.50	pre	9.5	27.5 d ± 37.4	0.6 d ± 1.0	0.3 a ±0.5	0.5 c ± 1.1
1.00	pre	9.8	3.0 d ± 4.8	0.03 d ± 0.05	0.0 a	0.0 c
0.25	post 3-wk	5.3	139.3 c ± 56.9	4.5 c ± 2.9	2.0 a ±1.4	40.8 a ±31.0
0.50	post 3-wk	8.0	77.5 cd ± 53.8	1.2 d ± 1.2	1.3 a ±0.5	43.7 a ±17.0
1.00	post 3-wk	8.3	54.3 d ± 6.6	0.5 d ± 0.2	1.0 a ±0.8	15.2 c ±20.9
0.25	post 6-wk	0.0	250.5 ab ± 57.9	10.0 ab ± 1.5	2.3 a ±2.1	8.0 bc ± 6.1
0.50	post 6-wk	0.0	269.5 ab ± 74.9	8.7 b ± 1.6	4.8 a ±4.6	29.3 ab ±21.9
1.00	post 6-wk	0.0	236.3 b ± 79.3	6.0 c ± 0.6	3.8 a ±2.8	16.1 bc ±13.3

[1] Timing: pre = before seedling emergence
post 3-wk = 3 weeks post-seedling emergence
post 6-wk = 6 weeks post-seedling emergence

[2] Plot area = 3.6 m^2.

[3] Means followed by the same letter are not significantly different at the 5% level, Duncan's multiple range test.

TABLE 5. Mean number of major weed species per plot for 1+0 Douglas-fir as of June 29-July 1, 1987, at three rates and timings of oxyfluorfen application (n=4)[1]

Treatment (kg a.i./ha)	Timing[2]	Black medick	Clover	Lamb's-quarters	Sedge	Shepherd's-purse	Striate knotweed
Hand-weeded	—	—	—	—	—	—	—
Non-weeded	—	7.8 ± 6.4	59.3 ±56.7	194.5 ± 16.0	13.8 ± 8.7	9.5 ± 6.0	7.8 ± 9.7
0.25	pre	12.0 ± 5.7	18.8 ±13.8	4.5 ± 3.4	0.0	0.0	0.8 ± 1.0
0.50	pre	8.5 ± 9.0	11.0 ±13.5	5.5 ± 11.0	0.3 ± 0.5	0.3 ± 0.5	0.0
1.00	pre	0.5 ± 1.0	2.3 ± 3.9	0.0	0.0	0.0	0.0
0.25	post 3-wk	22.3 ±15.7	59.3 ±56.7	1.5 ± 2.4	11.0 ± 2.5	10.8 ± 7.9	14.3 ±16.0
0.50	post 3-wk	18.3 ±17.4	34.3 ±30.8	0.0	4.8 ± 3.5	7.8 ± 7.3	2.8 ± 3.5
1.00	post 3-wk	12.8 ±10.9	20.8 ±14.6	0.3 ± 0.5	3.8 ± 2.2	4.3 ± 2.1	3.3 ± 1.7
0.25	post 6-wk	11.0 ±11.8	38.0 ±21.8	158.3 ± 57.2	7.3 ± 2.8	7.5 ± 3.4	7.3 ± 8.8
0.50	post 6-wk	9.0 ± 3.4	31.5 ±28.1	189.5 ± 79.2	8.8 ± 3.4	7.5 ± 5.6	5.8 ± 6.1
1.00	post 6-wk	6.5 ± 6.2	36.8 ±29.2	147.0 ± 74.0	13.3 ± 3.9	3.8 ± 1.9	10.0 ±11.8

[1] Plot = 3.6 m^2.
[2] Timing: pre = before seedling emergence
post 3-wk = 3 weeks post-seedling emergence
post 6-wk = 6 weeks post-seedling emergence

TABLE 6. Mean number of weed species in 2+0 lodgepole pine plots at three rates and timings of oxyfluorfen application (n=4)

Treatment (kg a.i./ha)	Timing[1]	Weed control rating (0-10)	Broadleaf	
			numbers per plot[2]	weight per plot (g)
Hand-weeded	—	10.0	—	—
Non-weeded	—	8.3	4.8 a[3] ±1.5	15.0 a ± 5.4
0.25	pre	9.8	0.3 b ±0.5	2.1 a ± 4.2
0.50	pre	9.0	0.5 b ±0.6	2.1 a ± 3.6
1.00	pre	9.8	0.0 b	0.0 a
0.25	post 3-wk	10.0	0.0 b	0.0 a
0.50	post 3-wk	10.0	0.0 b	0.0 a
1.00	post 3-wk	10.0	0.0 b	0.0 a
0.25	post 6-wk	9.8	0.3 b ±0.5	5.1 a ±10.1
0.50	post 6-wk	9.8	0.3 b ±0.5	21.2 a ±42.6
1.00	post 6-wk	10.0	0.0 b	0.0 a

[1] Timing: pre = before bud-break
post 3-wk = 3 weeks post-budbreak
post 6-wk = 6 weeks post-budbreak

[2] Plot area = 3.6 m^2.

[3] Means followed by the same letter are not significantly different at the 5% level, Duncan's multiple range test.

TABLE 7. Mean number of weed species in 2+0 Douglas-fir plots at three rates and timings of oxyfluorfen application (n=4)

Treatment (kg a.i./ha)	Timing[1]	Weed control rating (0-10)	Broadleaf	
			numbers per plot[2]	weight per plot (g)
Hand-weeded	—	10.0	—	—
Non-weeded	—	7.0	7.8 a[3] ±4.3	144.0 a ± 38.9
0.25	pre	10.0	0.8 a ±0.5	5.3 b ± 7.1
0.50	pre	9.3	1.3 a ±1.3	23.8 b ± 42.0
1.00	pre	10.0	0.3 a ±0.5	< 0.1 b < ± 0.1
0.25	post 3-wk	7.3	7.3 a ±9.2	168.7 a ±161.0
0.50	post 3-wk	9.5	1.3 a ±1.0	23.8 b ± 35.9
1.00	post 3-wk	9.5	1.3 a ±0.5	6.7 b ± 6.8
0.25	post 6-wk	7.3	7.5 a ±7.8	99.4 ab ± 97.8
0.50	post 6-wk	8.5	4.8 a ±2.2	72.7 ab ± 42.4
1.00	post 6-wk	9.3	3.0 a ±2.9	24.7 b ± 31.7

[1] Timing: pre = before budbreak
post 3-wk = 3 weeks post-budbreak
post 6-wk = 6 weeks post-budbreak

[2] Plot area = 3.6 m^2.

[3] Means followed by the same letter are not significantly different at the 5% level, Duncan's multiple range test.

TABLE 8. Mean number of seedlings/0.25 m^2 in 1+0 lodgepole pine and Douglas-fir plots at three rates and timings of oxyfluorfen application (n=8)

Treatment (kg a.i./ha)	Timing[1]	Mean number of seedlings	
		1+0 Pine	1+0 Fir
Hand-weeded	—	45.1 a[2] ± 5.1	38.0 a ± 7.0
Non-weeded	—	39.8 ab ± 9.1	27.9 bc ± 5.5
0.25	pre	38.6 ab ± 5.9	32.4 ab ± 8.9
0.50	pre	36.0 b ± 8.8	31.5 b ± 4.3
1.00	pre	23.9 c ± 4.8	27.1 bcd ± 4.1
0.25	post 3-wk	41.5 ab ± 7.9	24.6 cd ± 5.9
0.50	post 3-wk	40.8 ab ± 4.4	21.5 d ± 4.4
1.00	post 3-wk	41.3 ab ± 6.2	14.4 e ± 5.4
0.25	post 6-wk	41.6 ab ± 3.8	34.5 bc ± 3.5
0.50	post 6-wk	38.1 b ± 5.3	29.6 bc ± 4.7
1.00	post 6-wk	38.9 ab ± 7.0	29.9 bc ± 3.9

[1] Timing: pre = before seedling emergence
post 3-wk = 3 weeks post-seedling emergence
post 6-wk = 6 weeks post-seedling emergence

[2] Means followed by the same letter are not significantly different at the 5% level, Duncan's multiple range test.

TABLE 9. Plant tolerance ratings and the means of four growth parameters in 1+0 lodgepole pine at three rates and timings of oxyfluorfen application (height and root collar diameter, n=160; dry shoot and root weight, n=32)

Treatment (kg a.i./ha)	Timing[1]	Plant tolerance rating (0-10)	Height (cm)	Root collar diameter (mm)	Dry shoot weight (g)	Dry root weight (g)
Hand-weeded	—	10.0	11.0 a[2] ±2.9	3.1 b ±0.7	8.55 b ± 1.65	2.86 b ±0.51
Non-weeded	—	4.0	4.8 f ± 1.4	2.0 e ±0.5	3.02 f ± 0.80	1.73 e ±0.44
0.25	pre	9.5	9.9 b ± 2.6	3.0 b ±0.8	7.75 c ± 2.35	2.62 b ±0.70
0.50	pre	9.3	10.2 b ± 3.9	3.0 b ±0.9	9.25 b ± 3.44	2.62 b ±0.68
1.00	pre	8.1	8.5 c ± 3.0	3.2 a ±0.8	10.05 a ± 3.75	3.31 a ±0.92
0.25	post 3-wk	8.8	7.7 d ± 2.8	2.5 c ±0.6	5.13 e ± 1.85	2.21 c ±0.62
0.50	post 3-wk	6.8	7.6 d ± 2.7	2.6 c ±0.7	6.11 d ± 2.15	2.23 c ±0.69
1.00	post 3-wk	6.3	7.4 d ± 2.6	2.5 c ±0.7	5.57 de ± 5.57	2.08 cd ±0.55
0.25	post 6-wk	5.2	5.4 e ± 1.7	2.1 d ±0.5	3.38 f ± 0.83	1.79 de ±0.51
0.50	post 6-wk	5.7	5.5 e ± 1.6	2.0 d ±0.51	3.18 f ± 1.28	1.82 de ±0.72
1.00	post 6-wk	6.6	5.6 e ± 1.6	2.1 d ±0.4	3.47 f ± 0.71	1.96 cde ±0.37

[1] Timing: pre = before seedling emergence
post 3-wk = 3 weeks post-seedling emergence
post 6-wk = 6 weeks post-seedling emergence

[2] Means followed by the same letter are not significantly different at the 5% level, Duncan's multiple range test.

TABLE 10. Plant tolerance ratings and the means of four growth parameters in 1+0 Douglas-fir at three rates and timings of oxyfluorfen application (height and root collar diameter, n=160; dry shoot and root weight, n=32)

Treatment (kg a.i./ha)	Timing[1]	Plant tolerance rating (0-10)	Height (cm)	Root collar diameter (mm)	Dry shoot weight (g)	Dry root weight (g)
Hand-weeded	—	10.0	17.7 b[2] ± 4.7	2.9 ab ±0.7	8.61 b ± 2.47	3.15 a ±0.79
Non-weeded	—	5.1	11.3 f ± 3.9	2.2 d ±0.5	3.20 d ± 1.07	1.54 f ±0.44
0.25	pre	9.3	18.9 a ± 5.6	3.6 a ±0.8	10.18 a ± 3.43	3.11 ab ±0.80
0.50	pre	8.3	17.1 bc ± 5.0	2.9 b ±0.8	8.29 b ± 2.84	2.80 bc ±0.82
1.00	pre	6.8	16.3 c ± 5.3	2.8 b ±0.9	7.86 b ± 2.67	2.63 c ±0.82
0.25	post 3-wk	8.3	12.5 de ± 5.1	2.5 c ±0.8	4.83 c ± 1.99	2.07 d ±0.73
0.50	post 3-wk	7.0	12.3 f ± 5.2	2.5 c ±0.8	5.12 c ± 2.07	2.18 d ±0.82
1.00	post 3-wk	5.3	12.2 ef ± 5.5	2.5 c ±0.8	5.45 c ± 2.39	2.00 d ±0.76
0.25	post 6-wk	8.0	13.5 d ± 3.7	2.5 c ±0.6	4.55 c ± 1.36	1.99 d ±0.54
0.50	post 6-wk	8.5	12.2 ef ± 3.4	2.3 d ±0.6	3.52 d ± 0.84	1.62 ef ±0.29
1.00	post 6-wk	7.7	13.5 d ± 3.8	2.5 c ±0.6	4.65 c ± 1.18	1.92 e ±0.50

[1] Timing: pre = before seedling emergence
post 3-wk = 3 weeks post-seedling emergence
post 6-wk = 6 weeks post-seedling emergence

[2] Means followed by the same letter are not significantly different at the 5% level, Duncan's multiple range test.

DISCUSSION

At Surrey Nursery, seedling tolerance to oxyfluorfen treatments was strongly linked to seedling age. In general, herbicide effects were most apparent during the seedlings' succulent stage. Both 1+0 fir and pine tolerated the pre-emergence 0.25 kg a.i./ha application of oxyfluorfen, but the 0.50 and 1.00 kg a.i./ha rates substantially reduced seedling densities. At 3 weeks post-emergence, the two conifer species showed low tolerance to oxyfluorfen treatments, with reductions in all growth parameters. Pot experiments conducted by Richardson *et al.* (1984) with Douglas-fir, lodgepole pine, and Sitka spruce showed reduced seedling densities from 13 to 55% at rates of 1 and 2 kg a.i./ha, particularly in pine. Oxyfluorfen trials on loblolly pine (*Pinus taeda*) using a field rate of 3.0 kg a.i./ha showed that seedling emergence was reduced by 33%, but tolerance increased with age (South 1984). South and Mexal (1983) found that when loblolly pine was exposed to a soil mix of oxyfluorfen at 1.56 kg a.i./ha, seedling mortality increased by 46-63% and height was generally reduced by 45%.

It has been suggested that the thickness of the epicuticular wax on very young seedlings is too thin to act as a protective layer against the effects of oxyfluorfen (South 1982). As a result, oxyfluorfen is applied weekly in southern U.S. nurseries at very low rates (0.125 kg a.i./ha), and only after the last newly emerged seedlings have built up a protective wax layer (South and Springfield 1985).

The observed reduction in the 1+0 seedling growth in the 6-week post-emergence treatment plots was probably caused by severe weed competition. Because of the heavy canopy of weeds, the oxyfluorfen likely did not reach the seedlings. The effect was less pronounced in 1+0 fir, as this species is more shade-tolerant than the lodgepole pine. However, a definitive statement as to how much damage was actually due to the herbicide as opposed to weed competition is not possible based on the results of this trial. Further research is needed in which oxyfluorfen applications are studied at 3 and 6 weeks post-seedling emergence in the absence of weeds. Futhermore, under an operational situation conifer seedbeds would have been treated with both pre- and post-emergence applications during the season. Therefore, weed densities like those encountered in the 6-week post-emergence plots would not have occurred under normal circumstances.

At the 2+0 stage, neither pine nor fir showed a reduction in growth or densities at any rate or timing. Meakin and Orpin (1984) recorded no damage on 2+0 Douglas-fir, Sitka spruce, and Corsican pine that had been sprayed with oxyfluorfen at 0.50 kg a.i./ha before budbreak. As well, field trials on lodgepole pine in Idaho found that oxyfluorfen rates of 0.84 and 1.68 kg a.i./ha had little effect on seedling heights or densities (Sloan and Thatcher 1988).

In general, nearly all the weed species found in this trial were eliminated or significantly reduced, except for clover and black medic. The results also confirmed that weed species which have been reported as resistant to simazine, such as common groundsel and fireweed, were reduced or eliminated by oxyfluorfen (Meakin and Orpin 1984; Schlesselman and Lange 1984).

Oxyfluorfen applied 3 weeks post-seedling emergence in the 1+0 trial area was only effective at the 0.50 and 1.00 kg a.i./ha rates. Although increasing the rate of oxyfluorfen did improve the amount of weed control, it is believed that weeds eventually reach a size where they can tolerate the oxyfluorfen rates. Applications of oxyfluorfen 6 weeks after seedling emergence provided little or no control of the broadleaf weeds regardless of the rate of application. The weeds had grown to a size too large to be controlled. Studies in Ontario support these observations. Geier (1987) concluded that oxyfluorfen must be applied before the weeds reach the four- to six-leaf stage.

CONCLUSION

Pre-emergence applications at 0.25 kg a.i./ha of oxyfluorfen were found to be effective in controlling weeds, and were tolerated well by 1+0 and 2+0 Douglas-fir and lodgepole pine. Oxyfluorfen applications 3 weeks post-emergence provided adequate weed control, but had detrimental effects on growth and seedling densities in both conifer species. The effects of oxyfluorfen applications at 6 weeks post-emergence were confounded by severe weed competition, and this requires further study. All oxyfluorfen treatments were tolerated well by 2+0 Douglas-fir and lodgepole pine seedlings. Overall, seedlings from all 2+0 pine and fir treatment plots, as well as from the pre-emergence and 3-week post- seedling emergence plots in 1+0 pine, met or surpassed the minimum stock size specifications that are presently in use in British Columbia.

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APPENDIX 1.

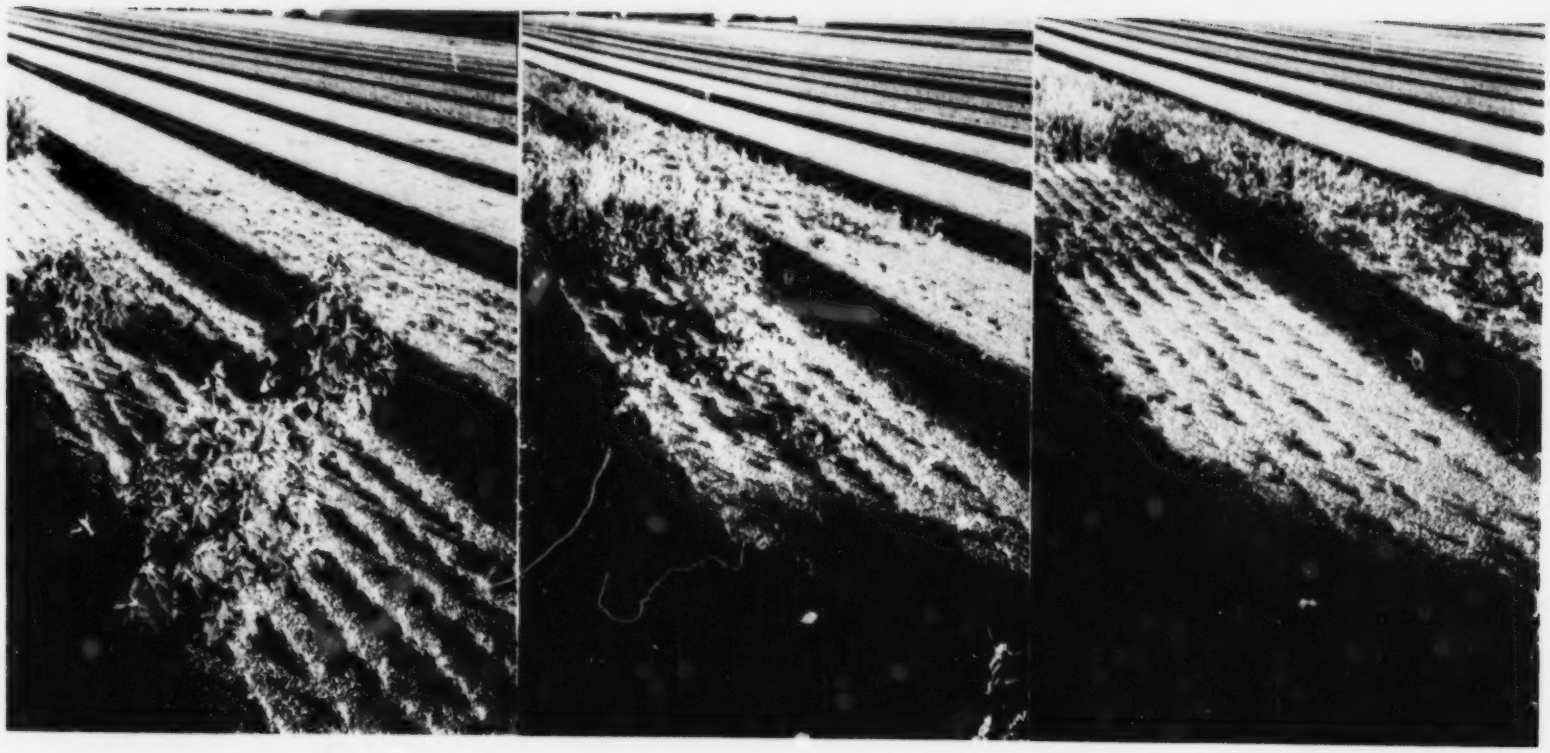
Photographs of Representative 1+0 Lodgepole Pine Trial Plots

Representative Control Plots — 1+0 lodgepole pine

Weeded

Non-weeded

Representative Pre-emergence Plots — 1+0 lodgepole pine

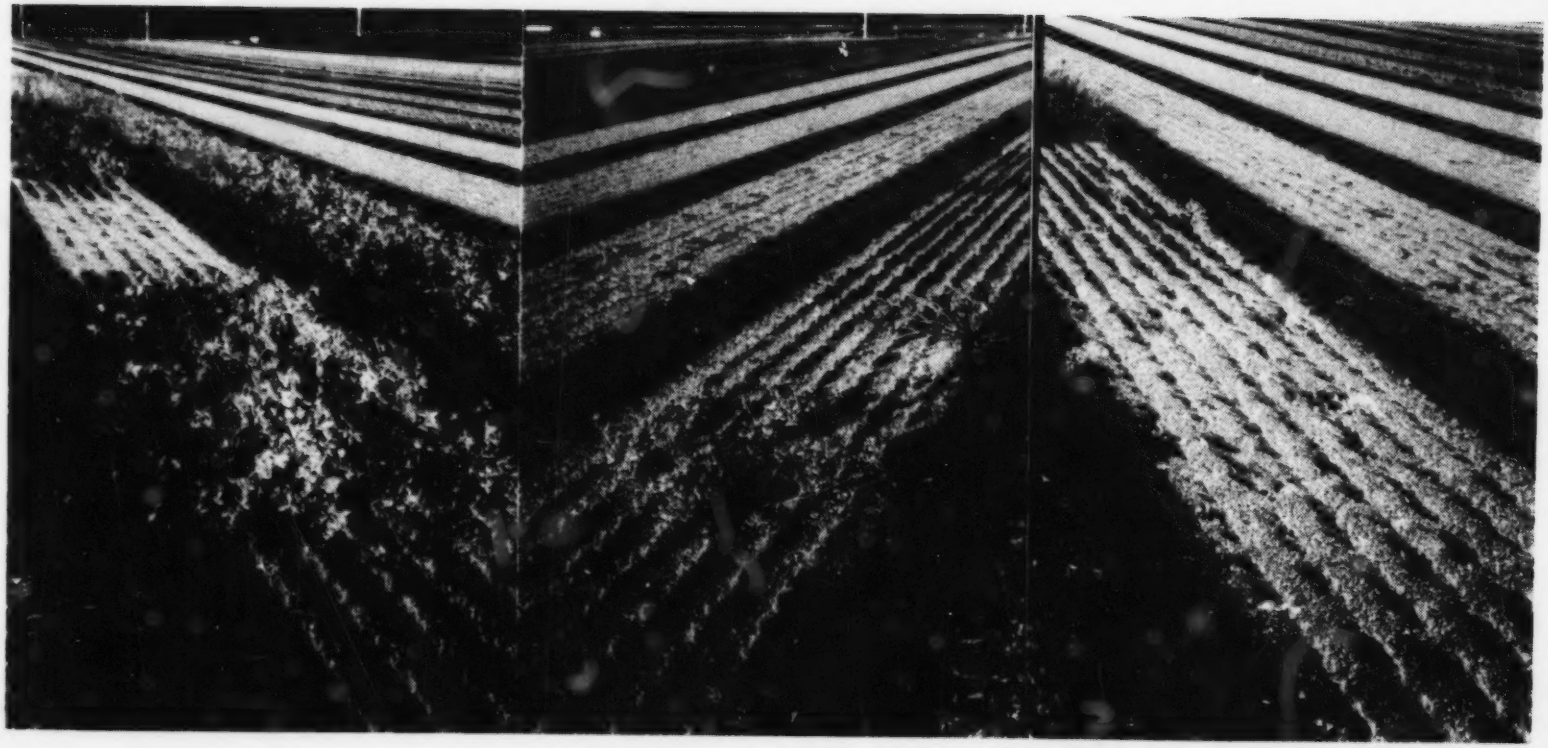


0.25 kg a.i./ha

0.50 kg a.i./ha

1.00 kg a.i./ha

Representative 3 weeks Post-emergence Plots — 1+0 lodgepole pine

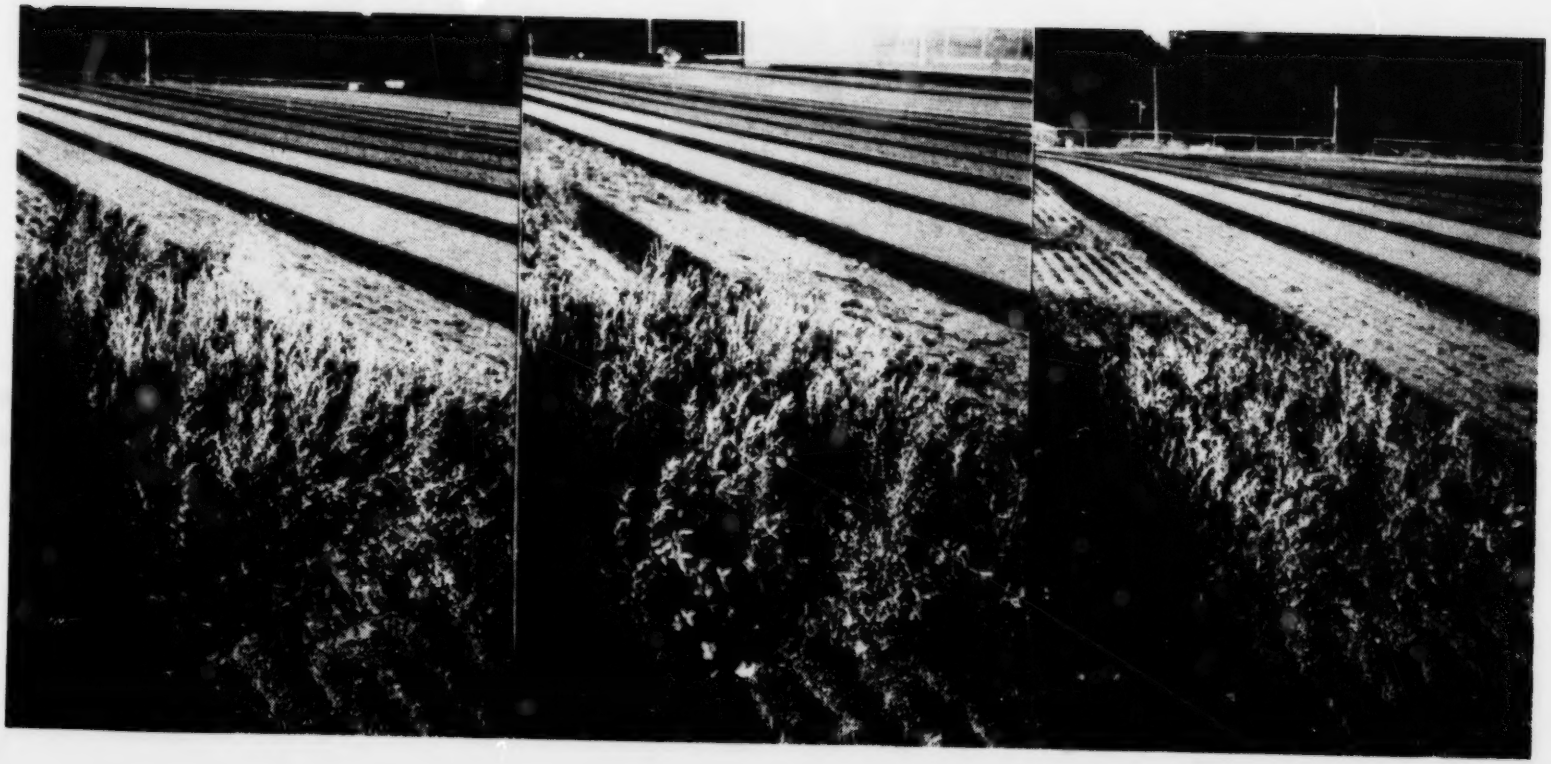


0.25 kg a.i./ha

0.50 kg a.i./ha

1.00 kg a.i./ha

Representative 6 weeks Post-emergence Plots — 1+0 lodgepole pine



0.25 kg a.i./ha

0.50 kg a.i./ha

1.00 kg a.i./ha